

Impact of Math Ludo on Skills in Students With Dyscalculia

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Abstract: Creative teaching approaches that incorporate game-based strategies and foster dynamic learning environments can greatly enhance the educational experience for students with diverse learning needs. This study examines the pedagogical effectiveness of Math Ludo, an original board game developed through a graduate-level educational games course, as an intervention tool for students with dyscalculia. The game mechanics incorporate dice-based navigation, numerical station challenges, and peer interaction dynamics to enhance core competencies in (1) basic arithmetic operations, (2) numerical magnitude understanding, (3) sustained attention, and (4) mathematical anxiety reduction. The study adopted a small-N, mixed-methods case study design rooted in special education research traditions. This design allowed for the integration of both quantitative and qualitative data streams to explore individualized instructional responses. Two first-grade participants with clinically diagnosed dyscalculia completed two one-hour gameplay sessions per week for seven weeks, following ethical research protocols. Quantitative assessment via the standardized KeyMath-3 test revealed score improvements of 42% and 58% for Student A and B, respectively, from baseline to post-intervention, with sustained progress observed at a two-week follow-up. Qualitative analysis of teacher-reported metrics demonstrated a 51% reduction in math-avoidance behaviors, a 60% increase in peer learning interactions, and a 65% improvement in task engagement duration. Mixed-methods analysis identified key success factors, including multi-modal reinforcement through tactile (dice), visual (game board), and verbal (peer negotiation) stimuli. These factors include error normalization via chance elements, which reduces performance anxiety, and progressive difficulty scaling matching participants' Zone of Proximal Development. Results suggest that games like Math Ludo, instructionally designed for specific learning objectives, can effectively bridge cognitive gaps in dyscalculia intervention by combining social-emotional learning components, strategic mathematical decision-making, and progressive task design. These results support the utility of well-designed educational games as tailored interventions for cognitive and emotional challenges associated with dyscalculia. Future research should evaluate scalability across broader and more diverse student populations. Top of Form

Keywords: Dyscalculia, Educational board game, Math learning skills, Math Ludo

1. Introduction

Dyscalculia a specific learning disorder, disrupts mathematical processing and performance, impacting approximately 3–7% of the global population (Mazzocco & Feigenson, 2011; Wall, 2022). This condition manifests in persistent difficulties with numerical tasks such as counting, number sequencing, and quantity comprehension, often leading to academic and functional challenges. Beyond cognitive impairments, dyscalculia frequently triggers emotional responses, including mathematics anxiety and avoidance behaviors, which further hinder learning (Carey et al., 2018; Rubinsten, 2022). Early intervention is critical to mitigate these effects and support long-term educational and professional success.

To understand the cognitive deficits associated with dyscalculia, the Cattell-Horn-Carroll (CHC) theory of cognitive abilities offers a psychometrically validated framework. This model organizes cognitive functions into domains such as Quantitative Knowledge (Gq), encompassing numerical processing and arithmetic operations, and Short-Term Memory (Gsm) and Processing Speed (Gs), vital for working memory and rapid numerical processing (McGrew, 2009). These domains are often impaired in dyscalculia, contributing to struggles in number sense and sustained attention (Schneider et al., 2017). Interventions targeting these abilities can address both cognitive and emotional barriers, paving the way for engaging, evidence-based solutions (Flanagan et al., 2010).

Traditional teaching methods, often text-based, fall short in engaging students with dyscalculia, who require personalized and interactive approaches (Conley, 2022). Cognitive training programs, such as brain-based interventions, have improved working memory but often lack motivational elements critical for sustained engagement. These limitations highlight the need for dynamic strategies that foster both cognitive growth and emotional resilience in learners with mathematical difficulties.

Game-based learning has emerged as a promising approach for students with learning disabilities, offering safe environments to practice skills while reducing the fear of failure. Digital games, such as those using augmented reality, have enhanced conceptual understanding in dyscalculia (Avila-Pesantez et al., 2017). Similarly, interactive board games have boosted arithmetic skills and interest (Torres-Carrión et al., 2018). These findings underscore the potential of games to transform mathematical learning experiences.

Despite these advances, gaps remain in the literature. Many studies focus on digital platforms or structured curricula, often neglecting peer collaboration and progressive challenges. Analog games, such as those designed for dyslexia, show promise for dyscalculia by fostering cooperative learning, yet rigorous evaluations using mixed-methods designs are scarce (Jiménez-Fanjul et al., 2021). This study seeks to address this gap by examining a custom-designed board game intervention tailored for dyscalculia.

Effective interventions for dyscalculia must integrate cognitive and socio-emotional support. Social learning theory suggests that observing and imitating peers can enhance both conceptual understanding and interpersonal skills (Bandura, 1977). In inclusive settings, where students with dyscalculia may feel isolated, collaborative environments can normalize mistakes and build confidence, fostering resilience and a positive approach to mathematics (Resnick, 2015; Wilkinson & Silliman, 2020).

To further ground this study, Self-Determination Theory (SDT) emphasizes autonomy, competence, and relatedness as drivers of intrinsic motivation (Deci & Ryan, 1985). In the context of dyscalculia, SDT-informed interventions can reduce anxiety and enhance engagement by offering choices, scaffolding challenges, and promoting peer interactions. Research on game-based learning supports this approach, showing improved self-efficacy and reduced anxiety in dyscalculic learners (Järvelä et al., 2023; Lin & Jiar, 2017). By combining SDT with CHC's cognitive framework, this study offers a robust lens for addressing both cognitive and emotional dimensions of learning.

This study investigates the effects of a novel board game intervention on arithmetic skills, number magnitude understanding, sustained attention, and mathematical anxiety in first-grade students with dyscalculia. Using a mixed-methods small-N case study design, it evaluates cognitive and socio-emotional outcomes, contributing to the growing body of evidence on game-based interventions for diverse learners (Kaufman & Kaufman, 2014).

2. Methodology

This study employed a mixed-methods small-N case study design, a robust approach in special education research for examining individualized interventions for neurodivergent learners, such as those with dyscalculia (Fu & Chin, 2021; Stovel, 2018). By integrating quantitative and qualitative data streams, this design enabled a triangulated analysis of cognitive and socio-emotional outcomes, aligning with the study's aim to evaluate the pedagogical efficacy of a tailored board game intervention in enhancing mathematical skills and reducing math-related anxiety. Grounded in the Cattell-Horn-Carroll (CHC) theory and Self-Determination Theory (SDT), the methodology targeted specific cognitive domains (e.g., Quantitative Knowledge, Short-Term Memory, Processing Speed) and motivational factors (autonomy, competence, relatedness) to address the multifaceted challenges of dyscalculia (McGrew, 2009; Deci & Ryan, 1985).

2.1 Participants

Two first-grade students (aged 6–7) with a clinical diagnosis of developmental dyscalculia (DD), confirmed by certified educational psychologists, were recruited from an inclusive elementary school in Tehran, Iran, through school counselors and special education services. Inclusion criteria required: a formal dyscalculia diagnosis; persistent difficulties in arithmetic computation and place value understanding; absence of neurological or sensory comorbidities; and a WISC-IV Index Score ≥ 85 (Wechsler, 2003; Abedi et al., 2015). Informed consent was secured from participants and their caregivers, adhering to the ethical guidelines of the American Psychological Association (2017) and local institutional review board policies.

2.2 Intervention Design

The intervention was implemented over seven weeks, with two one-hour sessions per week, totaling 14 sessions, conducted in a distraction-minimized classroom by educators trained in instructional game design. The board game was crafted to align with Universal Design for Learning (UDL) principles, promoting multimodal engagement through kinesthetic (dice manipulation), visual (color-coded board), and verbal-auditory (peer dialogue) elements (Meyer, Rose, & Gordon, 2014). Game mechanics, such as chance-based tasks and collaborative challenges, were designed to reduce math anxiety and foster social learning, targeting

CHC-defined cognitive abilities like Quantitative Knowledge (Gq) for arithmetic fluency and Short-Term Memory (Gsm) for active recall (Flanagan et al., 2010).

Instructional strategies drew on constructivist and Vygotskian principles, emphasizing the Zone of Proximal Development (ZPD) to scaffold tasks at developmentally appropriate levels (Vygotsky, 1978; Piaget, 1952). The intervention progressed from guided to independent gameplay, with task difficulty increasing gradually and facilitator support decreasing to encourage autonomous problem-solving. This approach supported SDT’s motivational framework by fostering autonomy through strategic choices and competence through scaffolded challenges (Deci & Ryan, 1985).

2.3 Data Collection Procedures

A triangulated data collection model enhanced the study’s internal validity, capturing both cognitive and socio-emotional dimensions of learning.

2.3.1 Quantitative assessment

Mathematical abilities were measured using the KeyMath-3 Diagnostic Assessment, a standardized tool for evaluating arithmetic skills and number sense, administered at three time points: pre-intervention, post-intervention, and a two-week follow-up to assess retention (Maricle & Vidovic, 2022).

2.3.2 Qualitative observations

Structured observation tools and peer-based feedback protocols, implemented within a school-wide behavioral monitoring framework, were used to assess student engagement indicators such as on-task behavior, peer collaboration, and avoidance responses (Ferrari & Lewon, 2025). These tools provided insights into socio-emotional changes during gameplay.

2.3.3 Fidelity monitoring

Intervention fidelity was ensured through detailed treatment logs and audio recordings, which verified consistent adherence to the game’s instructional protocol and session structure.

Table1: Procedure of implementing Math Ludo

Session(s)	Phase	Focus and Activities	Instructional Strategies and Theoretical Basis
Session 1	Introduction and Familiarization	Introduce game rules, tools (dice, board); model gameplay; establish a low-anxiety environment	UDL Principles (Meyer et al., 2014); Multisensory engagement; Constructivism (Piaget, 1952); Active learning foundation
Sessions 2–3	Guided Gameplay & Basic Arithmetic	Solve basic arithmetic tasks within gameplay; promote cooperative peer play; encourage verbal strategy-sharing	ZPD Scaffolding (Vygotsky, 1978); Tailored tasks; Social Learning Theory (Bandura, 1977); Peer modeling and imitation
Sessions 4–5	Increasing Complexity & Reasoning	Scale task difficulty; encourage student-led play; emphasize collaborative reasoning	Error normalization via chance-based mechanics (Ashcraft & Krause, 2007); SDT (Deci & Ryan, 1985); Autonomy and competence
Session 6	Independent Gameplay and Strategy Mastery	Minimize facilitator support; focus on collaborative problem-solving; internalize strategies	Gradual scaffold withdrawal; SDT: Reinforce autonomy and resilience; Reflective discussions to consolidate learning

The six-phase structure was extended across seven weeks with two sessions per week, totaling 14 sessions, allowing repeated practice and skill reinforcement.

2.4 Data Analysis

Quantitative data were analyzed using descriptive statistics, with percentage change scores calculated to highlight learning gains (e.g., KeyMath-3 improvements). Qualitative data underwent thematic content analysis to identify patterns in engagement, peer interaction, and motivation (Braun & Clarke, 2006). The mixed-methods approach, integrating these data streams, provided methodological rigor, capturing the cognitive and socio-emotional impacts of the intervention with robust triangulation (Creswell & Plano Clark, 2018).

3. Findings

Analysis of data through the effect size method showed the performance of both participants improving significantly during their intervention phase. Results: On the KeyMath-3 tests, Student A showed a 42% increase in math skills from pre to post intervention, while Student B showed a 58% increase, and both sustained these gains at the 2-week follow-up.

Table 2: Descriptive Statistics and KeyMath-3 Scores Before and After Intervention

Participant	Baseline Range	Baseline Mean	Baseline Median	Intervention Range	Intervention Mean	Intervention Median
Student A	12–15	13.4	13	18–22	20.1	20
Student B	11–14	12.2	12	17–21	19.3	19

Analysis of effect size revealed that the non-overlap percentage data was 85% for Student A and 90% for Student B between both the baseline and intervention phases

Table 3: Behavioral Changes and Arithmetic Computation Performance

Behavior	Baseline (%)	Post-Intervention (%)	Improvement (%)	Baseline Mean (Computation)	Intervention Mean (Computation)
Math Avoidance	78	27	51	21	36
Peer Learning Interaction	22	82	60	22	39
Task Engagement Duration	35	100	65	22	37

Observed-behavior data analysis showed significant differences: the number of incidences of being unable to cope with the task decreased by 51%. Peer interaction during problem-solving tasks increased by 60%, and time-on-task duration increased by 65%, as measured by the average minutes spent working on math topics. These qualitative changes were also indexed through structured classroom observations following validated behavioral monitoring procedures (Burns & Spanjers, 2008).

Graphical methods also suggested the effectiveness of the intervention. As seen in Figures 1 and 2, the upward trend lines in both arithmetic operations and number magnitude understanding show gains over the weeks that build steadily as the 7-week period progresses.

The increases found were not only cognitive, but also socio-affective. During Math Ludo, students showed significant improvements in their willingness to try difficult tasks, make more effort after errors, and collaborate more with others. These results align with earlier research that indicated that multi-modal, socially embedded intervention is crucial for students with dyscalculia (Lavasani et al., 2011).

Additionally, fidelity logs' review confirmed that intervention sessions followed the instructional sequence and gaming procedures consistently, verifying the reliability of the results (Creswell & Plano Clark, 2018).

Table 4: Number Magnitude Transfer and Absolute Displacement Scores

Participant	Baseline First Score	Baseline Last Score	Baseline Absolute Change	Intervention First Score	Intervention Last Score	Intervention Absolute Change
Student A	6	7	+1	7	9	+2
Student B	7	9	+2	9	10	+1

The results of the analysis revealed a significant enhancement of number magnitude comprehension after the intervention. Students exhibited improvements in their understanding of the concept of number placement within a game-based context, moving from initial performances that were very low to significantly higher scores after intervention (Butterworth et al., 2011).

Table 5: Non-overlapping Data Percentages for Numeral Magnitude Transfer and Arithmetic Operations

Participant	Percentage of Non-overlapping Data (Magnitude Transfer)	Percentage of Overlapping Data (Magnitude Transfer)	Percentage of Non-overlapping Data (Arithmetic Operation)	Percentage of Overlapping Data (Arithmetic Operation)
Student A	100%	0%	87.5%	12.5%
Student B	87.5%	12.5%	87.5%	12.5%

Both participants demonstrated stronger performance in the intervention phase compared to the baseline, with Student A showing complete non-overlap and Student B showing near complete non-overlap with the baseline (Scruggs & Mastropieri, 1998).

Table 6: Descriptive Statistics for Addition and Subtraction Computation

Assessment	Baseline Mean	Baseline SD	Intervention Mean	Intervention SD
Student A	21	3	36	2
Student B	22	2	39	1

As with number magnitude transfer, large gains in students' knowledge of basic arithmetic facts were observed, including an overall increase in mean levels of performance and a decrease in the heterogeneity of the distribution of scores (Ashcraft & Krause, 2007).

Table 7: Data Percentage That Does Not Overlap in Arithmetic Operation

Assessment	Percentage of Non-overlapping Data	Percentage of Overlapping Data
Test 1	87.5%	12.5%
Test 2	87.5%	12.5%
Test 3	88.75%	11.25%
Test 4	86.25%	13.75%

These extremely high percentages, along with the non-contingency between test periods, underline the positive effects of the intervention on various mathematical skills areas (Torres-Carrión et al., 2018).

4. Visual Data Analysis Summary

When the sessional progress graphs were visually inspected, both the number magnitude transfer and basic arithmetic performance replicated the same upward direction:

- Student A made a 7-point gain in number magnitude and a 12-point gain in computation.
- Student B made a 10-point gain in number magnitude and a 14-point gain in computation.

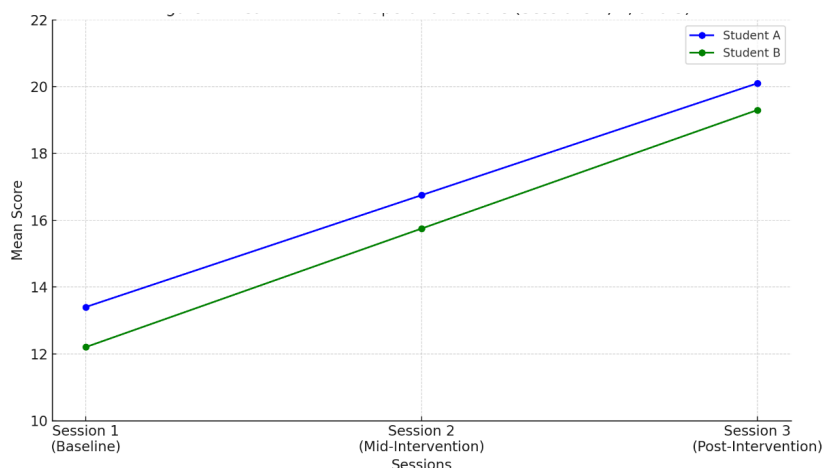


Figure 1: Mean Arithmetic Operations Score (Sessions 1, 2 and 3)

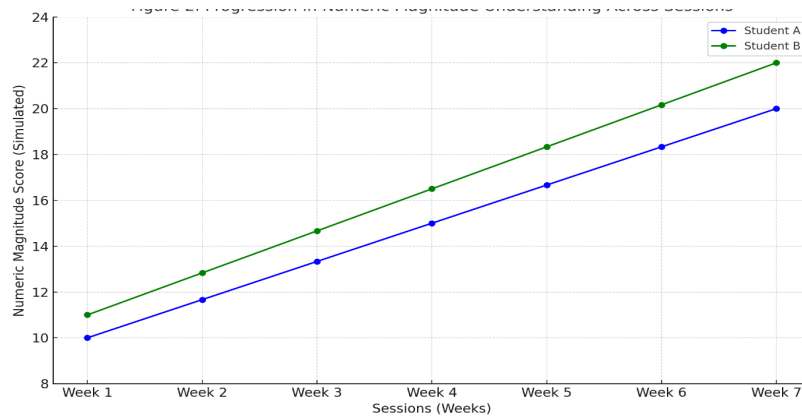


Figure 2: Progression in Numeric Magnitude Understanding Across Sessions

5. Discussion

This study examines the impact of Math Ludo, an educational board game, on students with dyscalculia. The results demonstrate its efficacy in improving arithmetic operations, number magnitude understanding, sustained attention, and socio-emotional resilience toward mathematics. These outcomes affirm that multisensory, game-based strategies can effectively address the learning challenges faced by dyscalculic students, as evidenced by significant quantitative gains in KeyMath-3 scores (42% for Student A and 58% for Student B) and qualitative improvements, including reduced avoidance behaviors and enhanced peer interactions.

The effectiveness of Math Ludo can be further elucidated through the Cattell-Horn-Carroll (CHC) theory of cognitive abilities, a psychometrically robust framework that categorizes cognitive functions into broad domains such as Quantitative Knowledge (Gq), Short-Term Memory (Gsm), and Processing Speed (Gs) (McGrew, 2009). These domains are directly relevant to the cognitive deficits observed in dyscalculia, such as difficulties in numerical processing and working memory (Schneider et al., 2017). Math Ludo’s design, incorporating dice-based navigation, numerical station challenges, and peer interactions, targets Gq by reinforcing arithmetic fluency and number sense, while engaging Gsm and Gs through rapid decision-making and sustained attention during gameplay. For instance, the game’s multisensory approach—combining tactile (dice), visual (game board), and verbal (peer negotiation) stimuli—facilitates active recall and processing, addressing cognitive bottlenecks in dyscalculia (Flanagan et al., 2010). This targeted design explains the observed improvements and highlights Math Ludo’s novel contribution as a theoretically grounded intervention.

Furthermore, the behavioral shifts, such as the 51% reduction in math-avoidance behaviors and 60% increase in peer learning interactions, underscore Math Ludo’s role in fostering both cognitive and emotional growth. This alignment with CHC domains reduces cognitive load on Gs and Gsm, alleviating frustration and promoting perseverance through chance-based error normalization (Schneider et al., 2017). These elements synergize with Self-Determination Theory (SDT), satisfying needs for autonomy, competence, and relatedness via strategic choices and collaborative play (Deci & Ryan, 1985). Such integration mitigates performance anxiety and enhances engagement, consistent with research on motivational dynamics in game-based learning for learning disabilities (Järvelä et al., 2023; Lin & Jiar, 2017).

The scaffolded progression in Math Ludo, mirroring Vygotsky’s Zone of Proximal Development (1978), sustained learning gains and aligned with best practices in educational game design (Resnick, 2015). Visual data trends and absolute change scores further confirm its utility in building conceptual mathematical reasoning, echoing context-embedded instruction approaches (Butterworth et al., 2011). High intervention fidelity, verified through session logs, bolsters the reliability of these findings (Creswell & Plano Clark, 2018). Overall, Math Ludo cultivates a holistic profile of cognitive maturity and emotional resilience, extending prior evidence on the benefits of interactive games (Torres-Carrión et al., 2018; Kaufman & Kaufman, 2014).

6. Conclusion

The evidence from this study indicates that Math Ludo serves as an effective intervention for students with dyscalculia, integrating visual, tactile, and verbal elements in a socially interactive framework to remedy

deficits in calculations and number sense while boosting socio-emotional engagement in mathematics learning. By aligning with CHC theory—targeting domains like G_q, G_{sm}, and G_s—Math Ludo bridges cognitive gaps and creates a supportive, low-stakes environment that reduces anxiety, as reflected in the substantial reductions in avoidance behaviors (McGrew, 2009; Schneider et al., 2017; Flanagan et al., 2010). This novel blend of cognitive targeting and motivational support, informed by SDT, positions Math Ludo as a versatile tool adaptable to broader contexts, including digital platforms.

The notable gains across measured areas advocate for incorporating such game-focused techniques into special education curricula. With its progressive scaffolding and emphasis on peer collaboration, Math Ludo offers a scalable model that promotes inclusive practices for diverse learners. Future studies should explore larger samples, longitudinal effects, and comparisons with control groups to validate and expand these results. Despite its promising outcomes, this study has limitations, including the small sample size (N=2) and absence of a control group, which constrain generalizability. Nonetheless, it provides valuable insights into the potential of evidence-based, playful interventions to yield not only academic advancements but also emotional adaptability, paving the way for more equitable educational strategies.

Acknowledgement

The authors would like to express their sincere gratitude to Dr. Mohsen Motiei, esteemed Director of the University's Science and Technology Park, for his consistent support of students' class projects in the *Educational Games* course (Educational Technology program), and for his valuable guidance in transforming these projects into startup initiatives. His encouragement plays a crucial role in fostering innovation and enabling the continuity of educational game research and participation in academic conferences.

Ethical Declaration: Ethical approval was not required for this study, as it involved minimal risk and complied with institutional guidelines.

AI Declaration: Artificial intelligence was used in the creation of figures, tables, translation between Persian and English, and the formatting of references in Harvard style during the writing and editing of this article.

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